Power Plant Retirements:
Trends and Possible Drivers

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Disclaimer

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Abstract

This paper synthesizes available data on historical and planned power plant retirements. Specifically, we present data on historical generation capacity additions and retirements over time, and the types of plants recently retired and planned for retirement. We then present data on the age of plants that have recently retired or that have plans to retire. We also review the characteristics of plants that recently retired or plan to retire vs. those that continue to operate, focusing on plant size, age, heat rate, and SO_2 emissions. Finally, we show the level of recent thermal plant retirements on a regional basis and correlate those data with a subset of possible factors that may be contributing to retirement decisions.

This basic data synthesis cannot be used to precisely estimate the relative magnitude of retirement drivers. Nor do we explore every possible driver for retirement decisions. Moreover, future retirement decisions may be influenced by different factors than those that have affected past decisions. Nonetheless, it is clear that recently retired plants are relatively old, and that plants with stated planned retirement dates are—on average—no younger. We observe that retired plants are smaller, older, less efficient, and more polluting than operating plants. Based on simple correlation graphics, the strongest predictors of regional retirement differences appear to include SO_2 emissions rates (for coal), planning reserve margins (for all thermal units), variations in load growth or contraction (for all thermal units), and the age of older thermal plans (for all thermal units). Additional apparent predictors of regional retirements include the ratio of coal to gas prices and delivered natural gas prices. Other factors appear to have played lesser roles, including the penetration variable renewable energy (VRE), recent non-VRE capacity additions, and whether the region hosts an ISO/RTO.

1 Introduction

There has been a significant amount of retirements of thermal generation assets in recent years, driven by a variety of market, policy, and plant-specific factors. There is uncertainty, however, on which factors have played the largest contributing roles.

- Average wholesale electricity prices have declined which, all else being equal, will erode the revenue possibilities of inflexible generation units (more-flexible units are in a somewhat better position to withstand average price declines, as they are able to dispatch around high- and low-priced periods).[1]
- Wholesale price reductions may be impacted by declining natural gas prices, growth in variable renewable energy (VRE), low load growth and high reserve margins, as well as other factors.
- New power plants may offer advanced technologies that enable improved heat rates, lower operating costs, lower emissions, and/or increased flexibility in operations, putting pressure on the economic position of older plants that use less-advanced technology.
- The operating costs of many existing plants are also rising over time, as those plants age and reach the end of their planned lifetimes and/or face increased regulatory pressures due to environmental regulations (e.g., coal and gas plants) or relicensing needs (nuclear and hydropower).
- A wide array of local, state, ISO/RTO, and federal requirements and incentives directed at power plants of all types and geographic locations also may be influencing retirement decisions.
- Finally, while retirements have increased recently, they have not done so in a vacuum, as generation capacity additions have also occurred, especially of natural gas, wind, and solar.

This paper synthesizes available data on historical and planned retirements. After describing our data sources, we present data on historical generation capacity additions and retirements over time, and the types of plants recently retired and planned for retirement. We then present data on the age of plants that have recently retired or that have plans to retire. We also review the characteristics of plants that recently retired or plan to retire vs. those that continue to operate, focusing on plant size, age, heat rate, and SO_2 emissions. Finally, we present various charts that depict the level of recent thermal plant retirements on a regional basis and correlate those data with a subset of possible factors that may be contributing to retirement decisions.

This basic data synthesis cannot be used to precisely estimate the relative magnitude of retirement drivers. Nor do we explore every possible driver for retirement decisions. Moreover, future retirement decisions may be influenced by different factors than those that have affected past decisions. Nonetheless, it is clear that recently retired plants are relatively old, and that plants with stated planned retirement dates are—on average—no younger. We observe that retired plants are smaller, older, less efficient, and more polluting than operating plants. Based on simple correlation graphics, the strongest predictors of regional retirement differences appear to include SO_2 emissions rates (for coal), planning reserve margins (for all thermal units), variations in load growth or contraction (for all thermal units), and the age of older thermal plans (for all thermal units). Additional apparent predictors of regional retirements include the ratio of coal to gas prices and delivered natural gas prices. Other factors appear to have played lesser roles so far, including VRE penetration, recent non-VRE capacity additions, and whether the region hosts an ISO/RTO or remains traditionally regulated.

2 Data and Methods

The data used in this paper come from several sources, summarized below:

- **Historical and planned retirements and historical additions data** primarily come from ABB's Velocity Suite dataset[2] (which, in turn, sources much of its data from EIA-Form 860M[3]). Historical distributed and utility-scale solar additions, however, come from GTM/SEIA and IREC.[4]
- **Summer non-coincident peak load** is estimated by simply summing the peak load of each region, as reported in ABB's Ventyx Velocity Suite.
- **Summer planning reserve margins** come from EIA-Form 411, updated as of March 2017.[5]
- **Power plant ages** come from ABB's Velocity Suite dataset.
- **VRE regional penetration** estimates come, in part, from annual wind generation reported in ABB's Velocity Suite divided by total generation in the region. For generators that had not yet reported 2016 data, we assumed 2015-level output after accounting for retired units. Since ABB does not include generation <1 MW and since large-scale solar generation data were substantially incomplete for the year 2016, we estimate solar generation based on state-level capacity, and regional capacity factors from NREL.[6] Distributed solar generation also added to total generation when calculating VRE penetrations.
- **Regional demand growth** comes from EIA's dataset of retail sales of electricity by state, with each state assigned to one of the ISO or non-ISO regions.[7]
- **Regional sulfur content** of coal comes from EIA's dataset on the quality of fossil fuels in electricity generation: sulfur content of coal by state.[8]
- **Regional and plant-level SO_2 emissions rates** come from ABB's Velocity Suite dataset.
- **Plant size and heat rate** both come from ABB's Velocity Suite dataset.
- **Delivered gas and coal prices**, by region, come from generation-weighted regional averages of the monthly power plant fuel costs between 2010-2016 reported in ABB's Velocity Suite dataset.

3 Retirements and Additions over Time

Figure 1 presents data on power plant retirements and additions over time, compared to national non-coincident peak load. Figure 2 segments recent retirements (2010-2016) and planned retirements (2017-2023) by generation type: coal plants, natural-gas steam (NGST) plants, combustion turbine (CT) plants, combined-cycle gas turbine (CCGT) plants, nuclear plants, hydropower plants, and other. The NGST category is broadly defined to include both natural gas and oil fired steam plants. Similarly, while most CTs are natural gas fired, some are primarily oil fired.

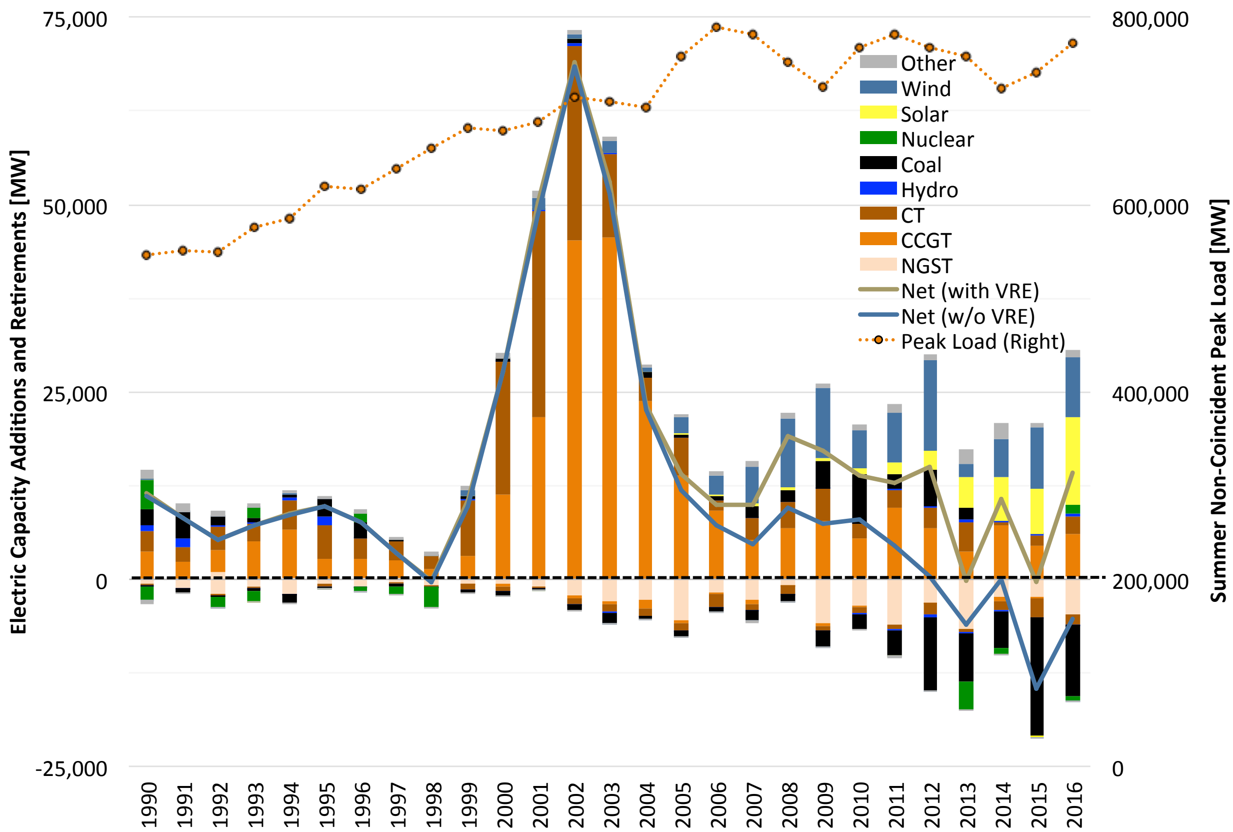
Several observations are apparent from these charts:

- Retirements of thermal plants have occurred throughout history, but have increased since 2010
- Coal & NGST units are the primary recent contributors, with CTs & nuclear a distant third and fourth
- As for planned retirements, coal, NGST, and nuclear plants are dominant
- Disregarding VRE, there has been a net loss of generation capacity nationally since 2012
- If VRE is included, however, net nameplate capacity additions have continued since that time[9]
- Historically significant levels of CCGT and CT additions are apparent from 2000-2005
- Historically significant levels of wind and then solar additions are apparent since 2007

- Non-coincident peak load was highest in 2006 and has not recovered to that peak as of 2016
- A net increase in thermal capacity exists since 2006 notwithstanding the lack of growth in peak load

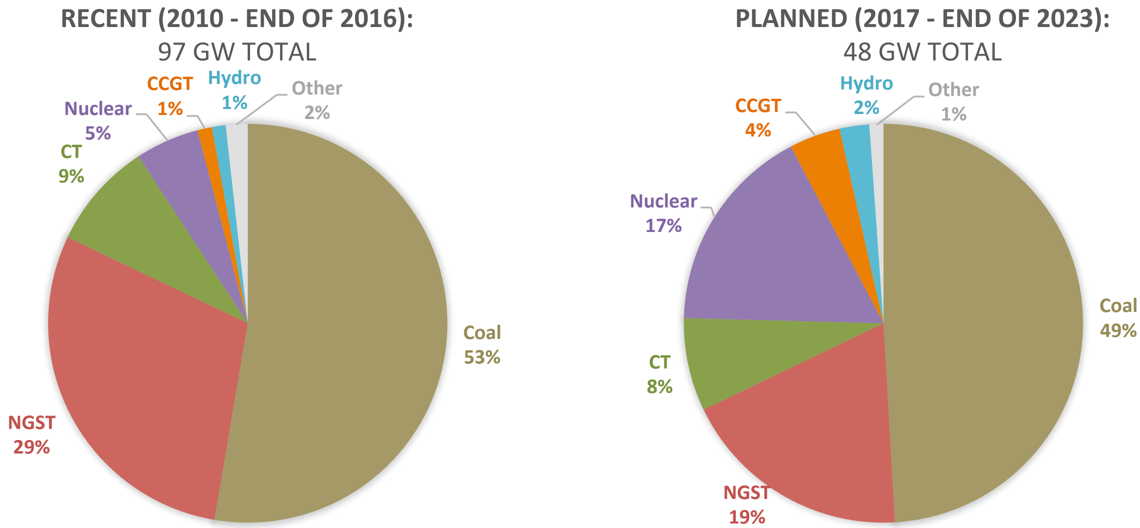
As a result of all of these trends, excess generation capacity exists nationally and regionally.[10]

Some caution should be applied to any interpretation of the planned retirement data, as actual retirements may differ substantially from what is presently planned and reported as such to EIA and other sources.



Source: LBNL analysis of ABB Velocity Suite Data, with solar estimates from IREC and GTM/SEIA

Figure 1. Retirements and Additions to the U.S. Generation Fleet over Time



Source: LBNL analysis of ABB Velocity Suite Data

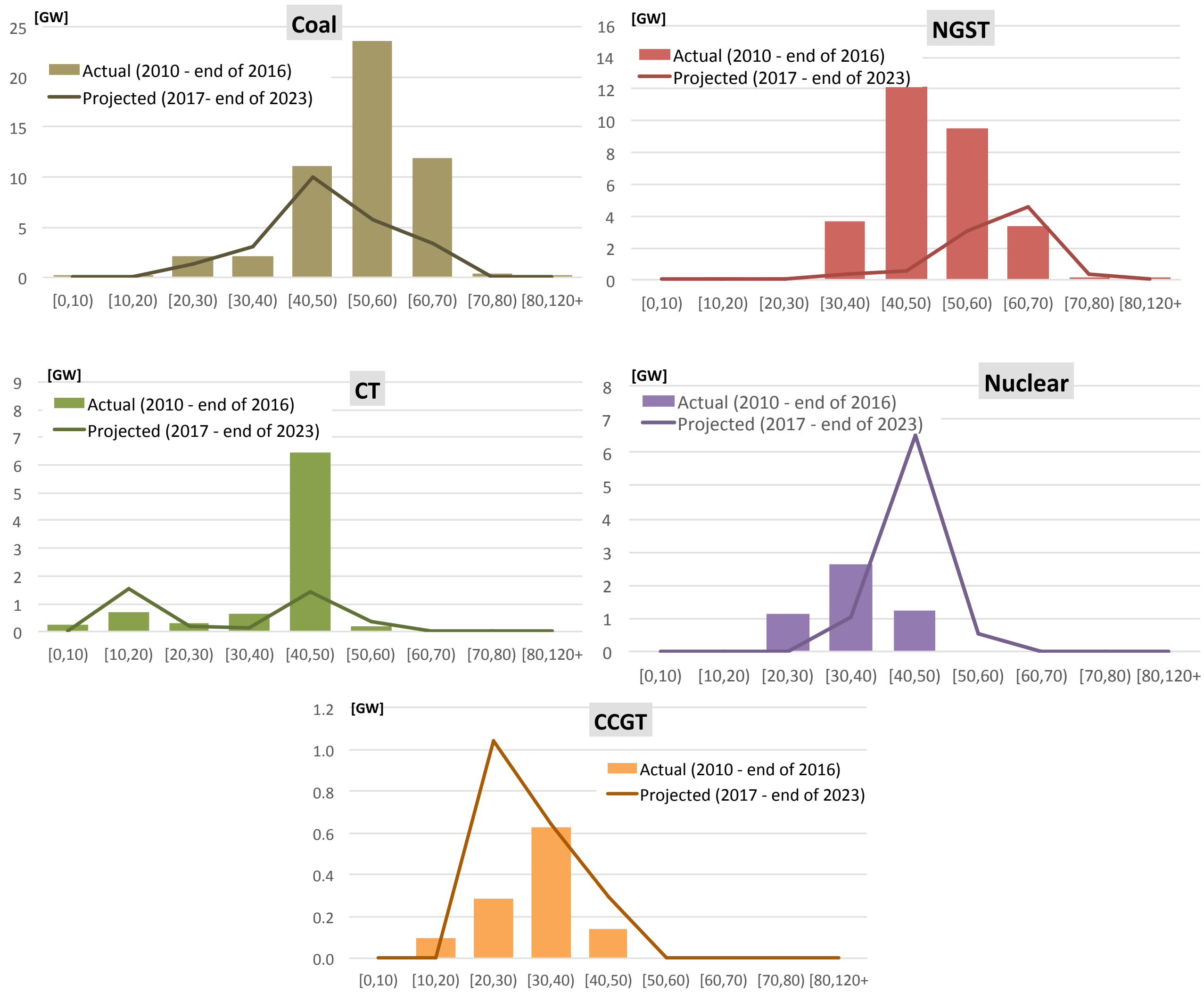
Figure 2. Plant Type Distribution for Recent and Planned Retirements

4 Project Age of Recent and Planned Retirements

Figure 3 presents histograms of project age of recent & planned retirements for coal plants, natural-gas steam (NGST) plants, combustion turbine (CT) plants, nuclear plants, and combined-cycle gas turbine (CCGT) plants.[11] Note the very different scale in each chart, with far larger amounts of retirements for some types of plants than others. Figure 4, meanwhile, presents trend lines for the age of retiring plants over time, while also extending the trend line to consider planned retirements.

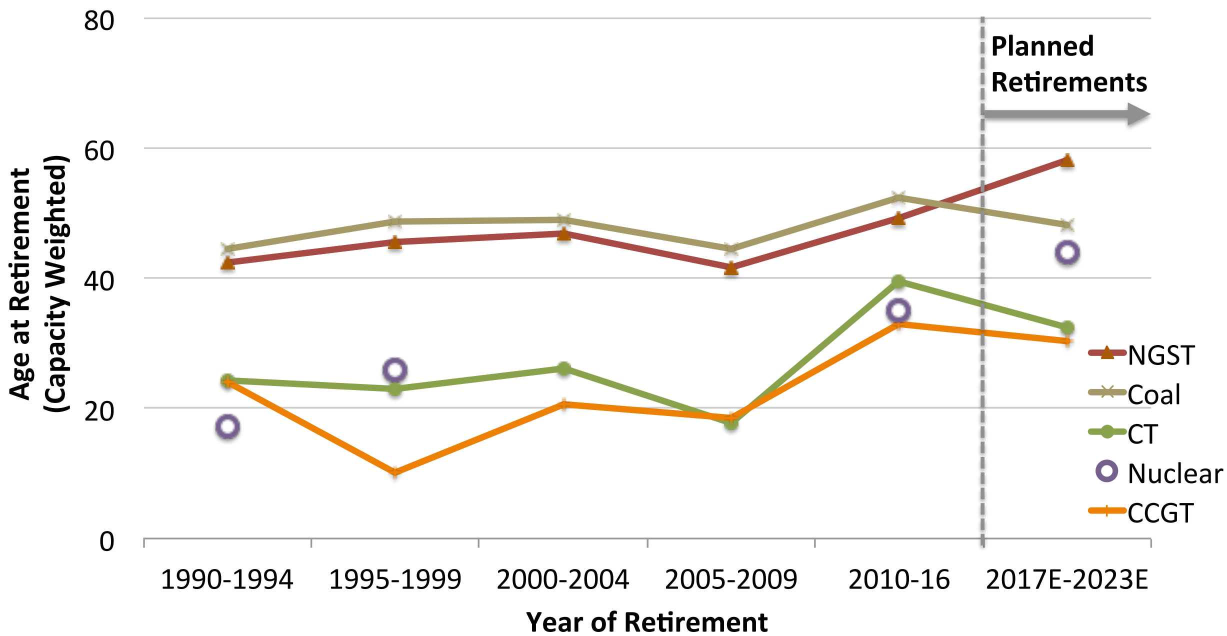
Several observations are apparent from these charts:

- Recently retired plants have been relatively old, across all generation types
  - The most common age of recently retired coal units is 50-60 years
  - The most common age of recently retired NGST units is 40-50 years
  - The most common age of recently retired CT units is 40-50 years
  - The most common age of recently retired nuclear units is 30-40 years
- Plants with announced retirement dates are also relatively old, based on expected age at retirement
  - Nuclear & NGST plants planned for retirement will be <u>older</u> than recently retired plants
  - Coal, CT & CCGT plants planned for retirement will be slightly <u>younger</u> than recently retired plants
- There is no observable broad historical trend towards retiring younger plants



Source: LBNL analysis of ABB Velocity Suite Data

Figure 3. Histograms of Project Age for Recent and Planned Retirements



Source: LBNL analysis of ABB Velocity Suite Data

Figure 4. Trend in Project Age of Past and Planned Power Plant Retirements

As noted earlier, caution should be applied to any interpretation of the planned retirement data, as actual retirements may differ substantially from what is presently planned and reported.

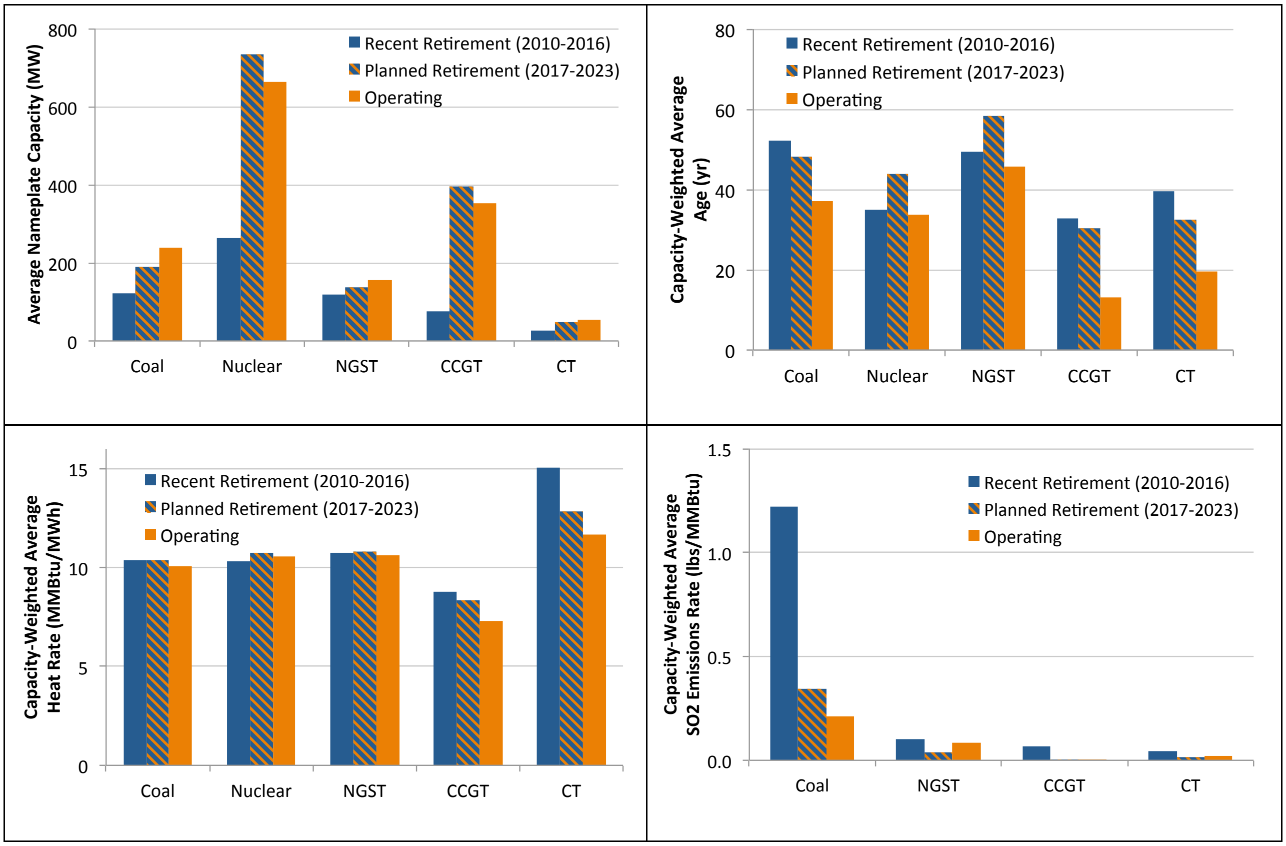
5 Comparison of Recently Retired Plants to Operating Plants

Figure 5 shows that the characteristics of plants that recently retired or that plan to retire are different than for plants that continue to operate with no immediate reported retirement plans. In particular, we observe that retired plants tend to be smaller, older[12], less efficient, and more polluting than operating plants. The figures demonstrate the following:

- Retired plants are smaller: Recently retired coal plants had an average capacity of 122 MW, whereas plants not scheduled for retirement are larger at 239 MW on average. Recently retired nuclear and gas-fired plants are similarly smaller than operating plants. Plants with planned retirement dates over 2017-2023 are larger, on average, than recently retired plants—more comparable to those plants that have not reported plans to retire in the near future.
- Retired plants are older: Coal plants that retired between 2010-2016 had an average age of 52 years while coal plants that did not retire and are not scheduled for retirement had an average age of 37 years in 2016. The recently retired gas plants are similarly older than operating plants. Recently retired nuclear plants, on the other hand, were only slightly older than the age of the operating plants. Plants with near term plans for retirement are also considerably older on average than plants with no such reported plans.
- Retired coal and gas plants are less efficient: The average heat rate of recently retired coal plants (10,386 Btu/kWh) was slightly higher than plants not scheduled for retirement (10,046 Btu/kWh), indicating that the plants that retired were also somewhat less efficient. The heat rate of recently

retired CCGT and CT plants, meanwhile, was considerably higher on average than plants not scheduled for retirement. Plants with near term plans for retirement are also less efficient than those plants with no immediate reported retirement plans.

- Retired coal plants are more polluting: The average emissions rate of coal plants that retired between 2010-2016 was 1.2 lbs SO_2/MMBtu, while the average emissions rate of the plants not scheduled for retirement was 0.2 lbs SO_2/MMBtu. Plants with announced retirements from 2017-2023 have emissions rates more consistent with those plants not reportedly planning to retire.



Source: LBNL analysis of ABB Velocity Suite Data

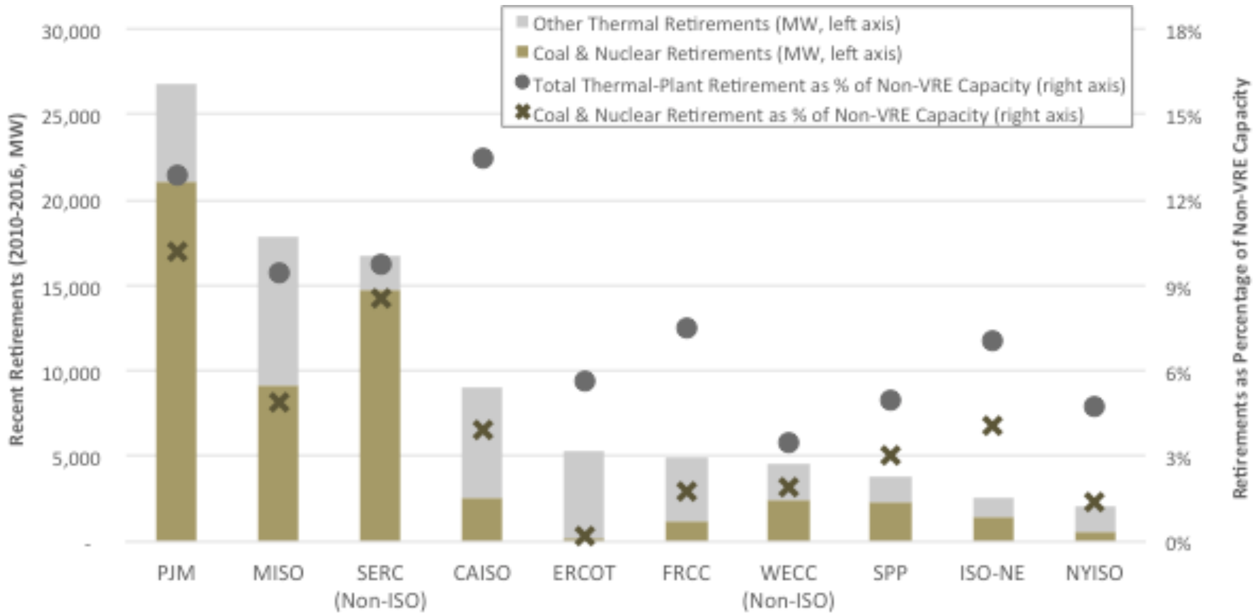
Figure 5. Comparison of Recently Retired or Planned Retirements to Operating Plants

6 Possible Drivers for Varying Levels of Regional Retirement

Figure 6 summarizes the regional distribution of recent retirements both for all thermal units and, of that total, the subset that includes only coal and nuclear units. The total thermal units category includes the NGST, CCGT, CT, Coal, and Nuclear categories used previously, while excluding the VRE, Hydro, and Other categories. The figure also normalizes these absolute sums by presenting them as a percentage of non-VRE capacity as of 2016 in each region.

In absolute magnitude, the largest amount of recent total thermal-plant retirements and coal & nuclear retirements have occurred in PJM, MISO, and the non-ISO portion of SERC. These same regions, along with CAISO, also have the largest amount of retirements on a percentage-of-non-VRE capacity basis.

Notably, natural gas plants dominate the recent retirements in ERCOT, CAISO, FRCC, and NYISO; coal and nuclear make smaller contributions.



Source: LBNL analysis of ABB Velocity Suite Data

Figure 6. Recent Thermal Plant Retirements, by Region

The final set of charts shown in Figure 7 correlate regional retirement percentages with a subset of factors that may be contributing to the strikingly different levels of recent retirement experienced in various regions. Most charts provide data points for both total thermal plant retirements and, separately, only coal and nuclear retirements. In some cases, however, the investigated factors are most likely to affect only coal and/or gas plants; we focus in those instances solely on those plant types.

Nine specific possible explanatory factors are explored:

- VRE penetration in percentage terms, considering utility-scale wind and PV and distributed PV
- Regional growth (or contraction) in electrical load from 2010 to 2016
- Average planning reserve margin (based on summer capacity and peak loads) from 2010 to 2016
- Average SO_2 emissions rates of the 25% of coal plants in each region with the highest emissions
- Average percent sulfur content of coal delivered to the region from 2010 to 2015
- Ratio of delivered coal prices to delivered gas prices in the region from 2010 to 2016
- Average regional delivered natural gas price from 2010 to 2016
- Average age of the oldest 25% of thermal power plants in the region in 2010
- New non-VRE capacity additions since 2010 as a percentage of total non-VRE capacity

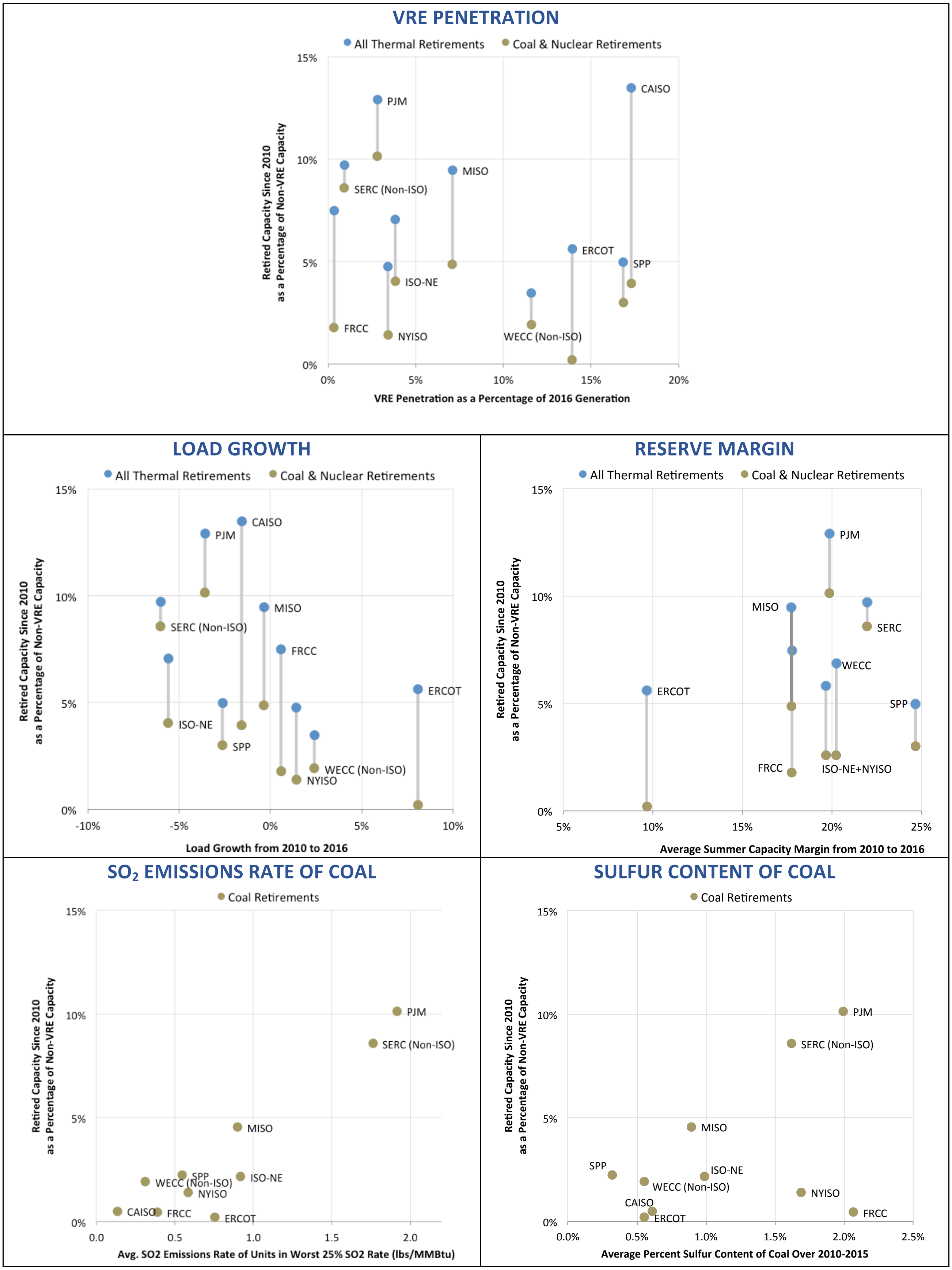
Visual inspection of these figures does not offer perfect clarity on the core drivers for regional retirement trends. Nor do historical trends necessarily tell us what might drive retirement decisions on a going-forward basis. However, we observe the following based on these graphics:

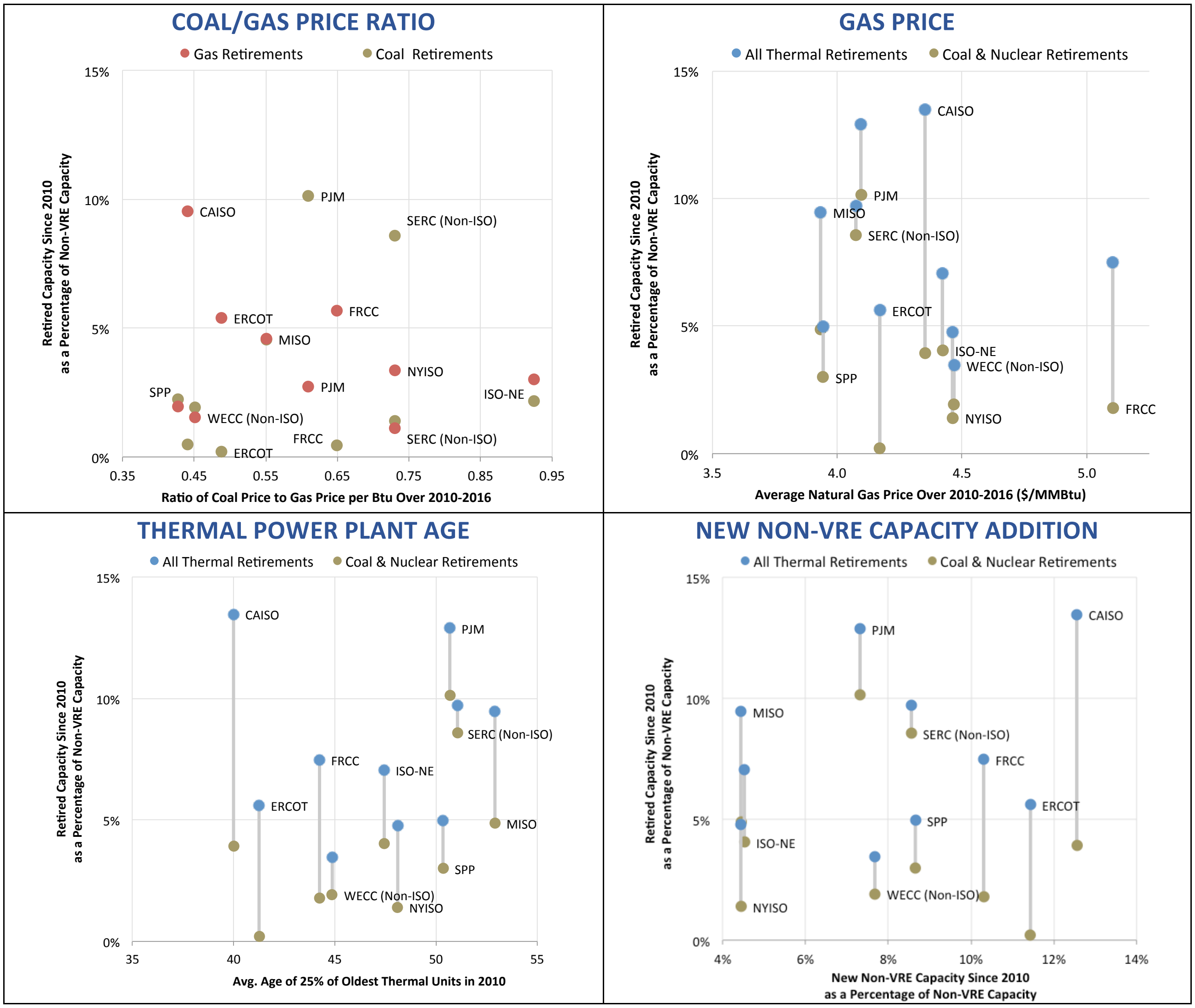
- *VRE Penetration:* There does not appear to be any obvious widespread relationship between VRE penetration and recent historical regional retirement decisions. PJM and SERC, both with very low

VRE penetrations, have among the largest amount of recent total thermal plant and coal & nuclear plant retirement. ERCOT, SPP, and the non-ISO portion of WECC, on the other hand, all have sizable VRE penetrations but low retirement percentages. CAISO has experienced strong growth in VRE and has the highest level of total thermal plant retirements on a percentage basis, most of which are older NGST plants; many of those plants have retired as a compliance mechanism with California's policy to phase out once-through cooling.[13]

- *Load Growth:* There appears to be a relatively strong inverse relationship between load growth and retirement percentages. Regions that have experienced load contraction from 2010 to 2016 tend to have larger amounts of retirement than those regions that have experienced growth.
- *Reserve Margins:* There appears to be a relatively strong relationship between summer planning reserve margins and retirement percentages. Regions with higher reserve margins from 2010 to 2016 tend to have larger amounts of retirement than those regions with lower reserve margins, perhaps suggesting an ongoing 'market correction' to existing levels of excess capacity.
- *SO_2 Emissions Rate of Coal:* One might anticipate that coal plants with high SO_2 emissions rates may be subject to more stringent environmental upgrade and retrofit needs, which may then drive retirement decisions. This relationship is clearly apparent in the graphic, suggesting that environmental compliance has been a key driver of coal retirements especially in PJM and SERC.
- *Sulfur Content of Coal:* The relationship between the average sulfur content of coal in the region and coal retirements is not as robust as for the SO_2 emissions rate, presumably reflecting adoption of control equipment in areas with high sulfur coal but lower emissions rates.
- *Coal-to-Gas Price Ratio:* Gas and coal compete in the dispatch stack, and there appears to be a weak relationship between the ratio of delivered coal-to-gas prices and the level of regional coal retirement. Some regions that have relatively lower cost coal and/or relatively higher cost natural gas have tended to experience a somewhat lower level of coal retirement. Some regions with inexpensive gas and/or high cost coal, on the other hand, have tended to see more coal retirement.
- *Gas Price:* It is widely recognized that reductions in natural gas prices have been a core driver for lower wholesale prices, and resulting thermal plant retirements. One might also expect that regions with relatively lower delivered gas prices might have experienced greater levels of retirement. A weak relationship of this nature appears to exist.
- *Power Plant Age:* One would expect that regions with older power plants might witness a greater amount of retirement. The graphic suggests that this relationship may exist, especially for coal & nuclear plants, with the notable exception of CAISO having significant retirements with relatively younger plants.
- *Non-VRE Power Plant Additions:* There does not appear to be a clear relationship between growth in non-VRE capacity additions since 2000 and the level of recent retirements.
- *ISO vs. Non-ISO Regions:* It is not obvious that the recent growth in thermal plant retirements is affected by whether the region has a wholesale market overseen by an ISO. SERC is traditionally regulated and has among the highest amount of retirement of all regions. The WECC (not including California) and FRCC also remain under traditional regulation, but have experienced relatively lower levels of retirement so far. Among the many regions with ISOs, retirement percentages vary widely.

Again, visual inspection of these charts is not dispositive in establishing causal relationships. Nor do these charts explore every possible driver for regional retirement variations. Moreover, future retirement decisions may be influenced by different factors than those that have affected past decisions. Nonetheless, based on these simple correlation graphics, the strongest predictors of regional retirement differences appear to include SO_2 emissions rates (for coal), planning reserve margins (for all thermal units), variations in load growth or contraction (for all thermal units), and the age of older thermal plans (for all thermal units). Additional apparent predictors of regional retirements include the ratio of coal to gas prices and delivered natural gas prices. Other factors appear, based on this simple analysis, to play lesser roles; these include VRE penetration, recent non-VRE capacity additions, and whether the region hosts an ISO or remains traditionally regulated.


VRE PENETRATION
All Thermal Retirements
Coal & Nuclear Retirements
Retired Capacity Since 2010 as a Percentage of Non-VRE Capacity
15%
10%
5%
0%
PJM
CAISO
SERC (Non-ISO)
MISO
ISO-NE
ERCOT
SPP
FRCC
NYISO
WECC (Non-ISO)
0%
5%
10%
15%
20%
VRE Penetration as a Percentage of 2016 Generation
LOAD GROWTH
All Thermal Retirements
Coal & Nuclear Retirements
Retired Capacity Since 2010 as a Percentage of Non-VRE Capacity
15%
10%
5%
0%
CAISO
PJM
MISO
SERC (Non-ISO)
FRCC
ERCOT
ISO-NE
SPP
WECC (Non-ISO)
NYISO
-10%
-5%
0%
5%
10%
Load Growth from 2010 to 2016
RESERVE MARGIN
All Thermal Retirements
Coal & Nuclear Retirements
Retired Capacity Since 2010 as a Percentage of Non-VRE Capacity
15%
10%
5%
0%
PJM
MISO
SERC
WECC
ERCOT
SPP
FRCC
ISO-NE+NYISO
5%
10%
15%
20%
25%
Average Summer Capacity Margin from 2010 to 2016
SO2 EMISSIONS RATE OF COAL
Coal Retirements
Retired Capacity Since 2010 as a Percentage of Non-VRE Capacity
15%
10%
5%
0%
PJM
SERC (Non-ISO)
MISO
WECC (Non-ISO)
SPP
ISO-NE
NYISO
CAISO
FRCC
ERCOT
0.0
0.5
1.0
1.5
2.0
Avg. SO2 Emissions Rate of Units in Worst 25% SO2 Rate (lbs/MMBtu)
SULFUR CONTENT OF COAL
Coal Retirements
Retired Capacity Since 2010 as a Percentage of Non-VRE Capacity
15%
10%
5%
0%
PJM
SERC (Non-ISO)
MISO
SPP
ISO-NE
WECC (Non-ISO)
NYISO
CAISO
ERCOT
FRCC
0.0%
0.5%
1.0%
1.5%
2.0%
2.5%
Average Percent Sulfur Content of Coal Over 2010-2015



Source: LBNL analysis of ABB Velocity Suite Data, along with supplemental sources as described earlier

Figure 7. Possible Drivers for Regional Retirement Trends

7 Future Research

This paper provides a cursory look at retirement trends and drivers, but by no means is the final word on the subject. To understand these trends and drivers in more detail would require an understanding of how each possible driver affects plant profitability, an exploration of additional drivers, and a better understanding of interactions among the possible drivers. Such analysis might usefully focus on specific resource types separately (e.g., coal, nuclear, or CCGTs), be conducted on a regional as opposed to solely a national basis, and consider planned as well as recent retirements. It may be useful to consider, for a wider variety of possible drivers, not only regional averages but the distribution of plants within those averages. Assessing retirement drivers over time, not only across regions, may be informative.

In conducting further analysis, additional drivers to consider include: (1) additional existing and prospective state, regional, and federal policies and regulations (e.g., carbon, NO_x, mercury, water, plant relicensing, RPS, etc.); (2) the specific impacts of wear-and-tear, cycling, and other factors on operational costs; (3) regional trends in wholesale energy and capacity prices; (4) the possible differential impacts of wind and PV, as opposed to the combined impact of VRE; and (5) thermal plant heat rates and capacity factors. Regression analysis and reviews of regulatory and financial filings offer useful tools to help better identify the underlying causes of investor decisions.

Endnotes and References

[1] Where active wholesale markets do not exist, the same basic dynamics hold: the declining cost of natural gas, for example, puts economic pressure on inflexible units even in markets that do not feature an ISO/RTO. Generation that is locked into longer term physical or financial contracts may be temporarily isolated from some of these forces, but will still be affected by, e.g., natural gas and wholesale price changes at least over the longer term.

[2] ABB Velocity Suite dataset. Accessed May 2017.

[3] https://www.eia.gov/electricity/data/eia860m/

[4] Specifically, GTM/SEIA data were used to estimate state-level solar capacity additions for the years 2010-2016 (GTM Research, Solar Energy Industries Association (GTM/SEIA). 2017. "U.S. Solar Market Insight, 2016 Year in Review", pp.51-57). State-level data from IREC were used to supplement capacity data for states that were not covered by GTM/SEIA in the years 2010-2013 and for solar capacity data for the years 1996-2009 (personal communication with Larry Sherwood, data are associated with the "U.S. Solar Market Trends" report series, 2006-2013, by the Interstate Renewable Energy Council (IREC)). http://www.irecusa.org/wp-content/uploads/2014/07/Final-Solar-Report-7-3-14-W-21.pdf.

[5] https://www.eia.gov/electricity/data/eia411/

[6] Specifically, we used the solar capacity data from GTM/SEIA and IREC to develop state-level solar generation data based on sector-specific capacity factor estimates reported by NREL (National Renewable Energy Laboratory. 2012. "U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis". http://www.nrel.gov/gis/re_potential.html). State-level solar generation data were then aggregated to ISO regions (future work could refine the state-level assignment to regions). California's solar generation is apportioned among CAISO and non-CAISO WECC based on EIA 861 NEM ratios for distributed solar and ABB's regional generation ratios for large-scale solar. We used ABB data for wind generation and total ISO generation data across all fuel types to calculate ISO-level VRE penetration levels.

[7] https://www.eia.gov/electricity/data/browser/. Future work could refine the state-level assignment to regions, or instead utilize different data sources.

[8] https://www.eia.gov/electricity/data/browser/. Future work could refine the state-level assignment to regions.

[9] Future work could look at net additions based on the estimated capacity credit of each resource type.

[10] See various NERC reports focused on existing, near term, and longer term reserve margins.

[11] We do not analyze hydropower retirements in more detail as some of the capacity categorized as retired is instead part of an uprating of a hydropower facility that continues operations. Overall, hydropower is a very small share of both historical and planned retirements.

[12] The age of plants is based on the age at retirement for plants that retired between 2010-2016, the age in the year that they plan to retire for plants slated to retire between 2017-2023, or the age in 2016 for operating plants that have not reported plans to retire over the timeframe considered here (2017-2023).

[13] California Energy Commission (CEC). 2017. "Once-Through Cooling Phase-Out." California Energy Commission. http://www.energy.ca.gov/renewables/tracking_progress/documents/once_through_cooling.pdf.